Washington State Department of Ecology
Toxics Cleanup Program

Tacoma Smelter Plume Site

King County Mainland Soil Study
Executive Summary

March 2002

Introduction

The ASARCO Tacoma Copper Smelter located in Ruston, Washington operated for approximately 100 years. It specialized in the toll smelting of complex (e.g., high arsenic content) ores and concentrates. Smelter operations ceased in 1986. The Tacoma Smelter was the dominant regional source of arsenic emissions; for many years, it was the sole domestic supplier of arsenic for the United States. The smelter also emitted significant quantities of lead, and lesser amounts of other metals associated with copper smelting.

The U.S. Environmental Protection Agency, Region 10 issued a Record of Decision (ROD) under Superfund for cleanup of soil contamination in the largely residential areas of Ruston and North Tacoma, Pierce County within about one mile of the smelter. ASARCO has completed several years of cleanup activities within that ROD area. Many properties have yet to be remediated.

Since 1999, the Washington State Department of Ecology (Ecology) has been investigating the regional extent of soil contamination from smelter emissions, under the state's Model Toxics Control Act (MTCA). The areas included in these studies are called the Tacoma Smelter Plume Site under MTCA. The first two studies, funded by Ecology and performed by Public Health - Seattle & King County (PHSKC), evaluated soil contamination on Vashon-Maury Island in King County. These initial studies focused on arsenic and lead concentrations in soils.

Soil samples were first collected and analyzed in the Fall of 1999 from relatively undisturbed forested locations in all areas of Vashon-Maury Island. A few samples were also collected from forested areas along the shoreline of the King County mainland as an initial exploratory study of that area. A report on the results of the initial Vashon-Maury Island study

was released by PHSKC in July 2000. Widespread soil contamination was documented.

The second Vashon-Maury Island study collected soils from 34 child-use areas where possible exposures of young children to contaminated soils were of concern. The child-use areas sampled included schools, public parks and beaches, daycare centers, preschools, and camps. Soil contamination was also documented to varying degrees at most of these non-forested, developed properties. In general, contamination in developed child-use areas was less than in nearby undisturbed (forested) areas.

The initial sampling of shoreline areas of the King County mainland showed soil arsenic contamination well above the MTCA cleanup level of 20 parts per million (ppm) for unrestricted land use. Based on these results, as well as information from a number of other historic studies related to smelter emissions, Ecology and PHSKC collected and analyzed soil samples from a much larger area of the King County mainland in the Spring of 2001. That third regional study of Tacoma Smelter Plume Site soil contamination has now been completed.

This executive summary presents the major findings from these initial surveys of smelter contamination in King County mainland soils. The data collected on the mainland during the first Vashon-Maury Island study and then the more extensive followup study are described in the next section. The major characteristics of mainland soil contamination are briefly discussed under the headings of magnitude, spatial pattern, contaminant correlations, depth profiles, and local variability. Finally, the combined results from the Vashon-Maury Island and mainland studies to date are reviewed to provide a summary of current understanding of the overall magnitude and spatial distribution in King County of soil contamination from smelter emissions.

The soil investigations completed so far reflect only the early stages of the MTCA cleanup process for the Tacoma Smelter Plume Site. The primary objective of these initial studies has been to better define the magnitude and extent of soil contamination at a regional scale. Relatively undisturbed forested properties have been the preferred initial sampling locations. Forest soils are likely to have the highest remaining concentrations of contaminants deposited from smelter emissions and thus characterize the full magnitude of possible contamination. (Property development actions involving removing near-surface soils, importing clean soils, regrading, and tilling can dilute or remove contamination that fell on surface soils from smelter emissions). Much of the mainland study area is intensively developed. However, the remaining forested properties were sufficiently numerous and well-distributed to allow for an initial survey of forested as opposed to disturbed properties. These early studies are focused on determining how contaminated the soils are, which areas are comparatively most affected, and how far from the smelter soil contamination above MTCA cleanup levels extends.

King County Mainland Soils Data

Soils data for the mainland include 75 locations (mapped as 67 locations because some of the initial sampling locations are close together), 201 borings, and a total of 624 samples over an area of approximately 200 square miles. These numbers represent all samples collected at forested properties in both of the mainland investigations to date.

The exploratory sampling of shoreline areas of the mainland occurred in the Fall of 1999. Samples were collected from 16 locations from Burien in the north to Federal Way in the south. Twelve locations were sampled with only one boring, while the other four had three closely-spaced borings to evaluate local variability, for a total of 24 borings. Each boring was sampled at two depth intervals, 0-2 inches and 2-6 inches (denoted depth intervals 1 and 2), for a total of 48 samples. (Field duplicate samples collected for data quality assurance evaluations are omitted in this discussion of results). Arsenic and lead were analyzed in all 48 samples; cadmium was analyzed in 31 samples.

Sampling of mainland soils over a much larger area occurred in Spring 2001. Sampling locations included the area from West Seattle south to the Pierce County line in the western half of the study area and from I-90 south to Lake Youngs in the eastern half of the study area. The low-lying and frequently flooded Green-Duwamish River valley was not sampled because its soils are probably not representative of regional scale impacts from smelter emissions. Sampling extended about 12 miles inland from Puget Sound and to a maximum distance of almost 27 miles downwind from the smelter. This study area was chosen based on several types of information, including wind rose data showing primary transport directions for smelter emissions, historic studies such as precipitation chemistry studies by the University of Washington, and published studies showing soil impacts at distances of more than 20 miles at other major emissions sources.

The mainland sampling locations were selected based on a number of criteria intended to identify locations with among the largest smelter impacts. Only forested properties were sampled. Larger forested areas with more mature trees were generally favored over smaller areas with younger trees, where the likelihood of soil disturbance is greater and the period of accumulation of deposited contaminants is shorter. Steep slopes and floodplains where significant physical erosion and deposition of soils occur were excluded. Gentle slopes facing toward the smelter were preferred over lee slopes where less deposition occurs. Locations close to major roadways and major painted structures were avoided to reduce impacts from recognized non-smelter sources for metals.

Three closely-spaced borings were sampled at each of 59 locations, for a total of 177 borings. Multiple borings were sampled at each location with an expectation of substantial local variability, based on previous results, and to better characterize upper-bound concentrations of soil contamination. All borings were sampled at three depths: 0-2 inches, 2-6 inches, and 6-12 inches (denoted depth intervals 1, 2, and 3). Forty-five borings at 15 locations in the west-central portion of the study area, where impacts were expected to be greatest, were also sampled

at a fourth depth of 12-18 inches to provide additional information on soil contamination depth profiles. A total of 576 soil samples was collected and analyzed in the extended mainland investigation.

All 576 samples in the extended mainland study were analyzed for arsenic and lead. These two elements are the primary contaminants of concern for possible threats to human health and the environment from smelter emissions. Only the results for arsenic and lead are discussed in the rest of this executive summary. Analyses for additional elements, to evaluate likely sources for arsenic and lead, were performed for 68 soil samples selected from 33 of the 59 sampling locations in the extended mainland study. The results of analyses for these additional tracer elements related to smelter emissions are undergoing data validation reviews and will be reported separately. (The maximum cadmium concentration for the 31 samples analyzed in the first mainland sampling was 3.6 ppm. Those cadmium results will be included in the evaluation of tracer element analyses).

A complete listing of the arsenic and lead results for all 624 mainland samples is provided as an attachment (see Table 1). Sampling locations are shown and labeled by designated sample codes on Figure 1. Sampling design information, including the number of borings and depth intervals sampled by location, is provided on Figure 1a. Both of these maps, and subsequent data summary maps, include information for the initial survey of Vashon-Maury Island (see the discussion of Combined Vashon-Maury Island and King County Mainland Results, below).

Magnitude of Contamination

Arsenic and lead concentrations for mainland King County samples range from below detection limits to values substantially above Puget Sound regional background concentrations, as determined in an earlier Ecology statewide survey of soil background values. The range of reported results spans approximately two orders of magnitude for both contaminants. The maximum concentrations are 260 ppm for arsenic and 790 ppm for lead. (All contaminant concentrations represent analyses of samples sieved to less than 2 mm and are reported on a dry weight basis). These maximum values exceed Ecology's MTCA unrestricted land use cleanup levels of 20 ppm for arsenic and 250 ppm for lead.

The widely varying results reflect local variability in concentrations, different levels of impact in different parts of the study area, and different effects by the soil depth sampled. Not all samples are expected to have similar levels of impact from smelter emissions. For example, in undisturbed forested areas most of the arsenic and lead contamination is retained in the near-surface, organic-rich soils. Low reported concentrations in deeper soils are common, regardless of the degree of contamination in shallower soils. The objectives of the mainland survey, to define the possible magnitude and extent of smelter-related soil contamination, are better

achieved by looking at the maximum contaminant concentrations at the 75 locations sampled rather than the 624 individual results.

Maximum reported arsenic concentrations by sampling location are shown on an attached map (see Figure 2). For arsenic, 62 of 75 sampled locations had a maximum concentration above the MTCA cleanup level of 20 ppm. Arsenic contamination to some degree was thus found to be widespread across the study area. The statistical distribution for maximum arsenic values is shown in an attached bar chart (see Figure 3). This asymmetric distribution is of a type called right-skewed, with a few results substantially higher than the rest.

A map of maximum lead concentrations is provided as Figure 4. Only 12 of 75 sampling locations had a maximum lead concentration above the MTCA cleanup level of 250 ppm. The statistical distribution for maximum lead values is shown on Figure 5; it is also right-skewed, with infrequent higher values. Comparison of these results for arsenic and lead confirms that lead exceedances are less widespread, and that arsenic is the primary smelter contaminant of concern with respect to MTCA cleanup decisions. Sources other than the Tacoma Smelter appear to contribute to soil lead concentrations on the mainland (see the discussion of the Relationship Between Arsenic and Lead, below).

The density of soil sampling on the mainland is fairly low, with about one location sampled per 3 square miles on average. The availability of any forested properties over much of the study area is quite limited. As a result, some locations were sampled despite less than optimal characteristics (e.g., with respect to slopes, elevations, or the maturity of tree cover) for representing maximum degrees of smelter impacts. Considering these factors, the mainland data from the initial mainland investigations could underestimate the true maximum contaminant concentrations in all parts of the study area (i.e., there is likely to be some degree of low bias in the reported results for characterizing maximum contamination levels). More extensive sampling in the future may show higher levels of contamination than are reported here.

The results from closely-spaced multiple borings at a sampling location show local variability in soil contamination. An average concentration can be calculated across borings for each sampled depth at a location to represent the general amount of contamination occurring at a spatial scale somewhat larger than the single sample maximum result. (When only one boring exists at a sampling locations, the averages by depth are by default the same as the single sample results). The magnitude of contamination summarized based on average results (the highest average concentration for any depth interval) is very similar to the pattern based on maximum concentrations. For arsenic, 43 of 75 sampling locations have a highest average concentration above the MTCA cleanup level of 20 ppm. The highest average arsenic results are 170 ppm for locations with one boring and 125 ppm for locations with three borings. For lead, only 5 of 75 sampling locations have a highest average lead concentration above the MTCA cleanup level of 250 ppm. The highest average lead results are 580 ppm for one boring and 453 ppm for three borings.

Spatial Pattern

The spatial distributions of maximum arsenic and lead concentrations across the mainland study area are shown on Figures 2 and 4. Even a cursory examination of these maps will reveal an unequal distribution of the maximum arsenic and lead results.

An analysis of the spatial patterns for soil contamination can be performed by considering subregions within the study area. Since wind rose patterns are the primary factor determining transport of smelter emissions downwind, one convenient way to divide the total study area is by wind rose sectors and distance from the smelter. (A wind rose has 16 sectors, each covering an arc of 22.5 degrees centered on a compass heading showing the wind directions, with information on the frequency and strength of winds by sector. Representative annual wind frequencies for the vicinity of the Tacoma Smelter, taken from a 1980 meteorological station record by the Puget Sound Clean Air Agency, are included on the data summary maps. Note that the relative wind frequencies are shown as directions toward which the winds blow). The mainland study area includes four wind sectors from the smelter, assuming linear wind fields: winds toward the NNE, NE, ENE, and E (see Figure 1). Of these, winds toward the NE are most frequent, followed by ENE. For winds toward the NE and ENE the mainland sampling locations divide naturally into two groups based on distance, separated by the Green-Duwamish River valley. This division by wind sector and distance thus results in six subregions within the total mainland study area.

Evaluating groups of sampling locations rather than individual locations is an appropriate way to assess spatial patterns at a regional scale. Local variability in results among sampling locations near each other is fairly high and does not correspond to the regional-scale pattern.

Statistical data summaries (e.g., percentile values) and concentration-by-distance plots of the arsenic and lead results for these six regions confirm the patterns found by visual observation on Figures 2 and 4. The spatial pattern is clearest for maximum arsenic results. The highest concentrations all occur near Puget Sound in the sectors with the most frequent winds (toward the NE and ENE), from approximately the north end of Normandy Park to the south end of Des Moines and southwest Kent. In these two wind sectors there is also an apparent gradient from higher concentrations near Puget Sound, closer to the smelter, to significantly lower concentrations at greater distances east of the Green River valley. Maximum arsenic results in areas to the north (to West Seattle) and south (to Federal Way) of the highest-impact zone are also consistent with wind frequencies. This spatial pattern is thus consistent with the smelter as the primary source for soil arsenic contamination on a regional scale. (Adding the Vashon-Maury Island results to those from the mainland strengthens this conclusion; see Combined Vashon-Maury Island and King County Mainland Results, below).

The locations sampled so far on the mainland are too limited to provide a detailed definition of the concentration gradients by distance and direction. For example, there are too few sampling locations inland from the highest-impact zone along the Puget Sound shoreline to define how fast concentrations fall off to the east. The mainland study area also does not appear to be large enough to define boundaries in King County for areas that could exceed MTCA soil cleanup levels. Maximum arsenic concentrations exceeding the cleanup level occur to the limits of the study area in all sampling regions.

The spatial pattern for maximum lead results is more diffuse than that for arsenic. This is consistent with the expectation that in addition to smelter emissions other significant sources for airborne lead - historic emissions from leaded gasoline, for example, and "urban plume" effects - are likely to affect soils in developed urban areas, while the smelter alone is the dominant identified source for airborne arsenic. Most of the highest maximum lead results still occur at sampling locations in the NE and ENE wind sectors near Puget Sound (see Figure 4). However, a few other high values occur elsewhere and there is more overlap in concentration distributions across the 6 defined subregions. An assessment of the relationship between soil arsenic and lead results contributes to an understanding of the likely role of smelter emissions as a contributor to mainland soil lead contamination.

Relationship Between Arsenic and Lead

Evaluations of the results from previous Vashon-Maury Island studies, as well as information from other sites and theoretical studies, have shown arsenic to be somewhat more mobile than lead in near-surface soils. As a result, when both arsenic and lead are deposited to soils from airborne emissions, they will tend to separate somewhat in the soil column over time. This can reduce the apparent degree of correlation between the two contaminants. The relationship between arsenic and lead concentrations is therefore evaluated based on maximum concentrations at any depth for the 75 sampling locations, to avoid artifacts from differences in mobility. A listing of maximum arsenic and maximum lead concentrations by sampling location is provided in Table 2.

The maximum arsenic and lead results from mainland sampling locations show a strong and statistically highly significant correlation. A scatterplot of maximum lead versus maximum arsenic results is attached (see Figure 6); note that the axes are log-scaled. A positive association of lead and arsenic values is apparent, even though there is considerable scatter in the individual data points. High arsenic values tend to occur together with high lead values. Statistical regression analysis confirms that the relationship so apparent in the data scatterplot is significant.[1]

[1] A multiplicative regression equation provides a better fit to the data than a linear equation. The regression model is Lead = 5.09 x Arsenic $^{0.88}$ (R-squared = 59%, $p<0.00001$).

The scatter in the plotted maximum lead versus maximum arsenic data from the mainland is somewhat greater than for comparable data from the initial Vashon-Maury Island study; that is, the results show more variability. The lead:arsenic ratios from the best-fit regression equation are also higher than those for Vashon-Maury Island (by about 30 percent). At locations where mainland soil arsenic concentrations are smaller and smelter impacts decrease, the lead:arsenic ratios are higher (see Figure 7). These patterns are all consistent with an independent contribution from one or more non-smelter sources for lead. However, the strongly correlated maximum arsenic and maximum lead results indicate that smelter emissions are also contributing to observed soil lead levels on the King County mainland at the locations sampled. Only a few of the mainland locations where arsenic concentrations were highest are close to major transportation corridors. This probably reduced, but did not totally eliminate, the influence of non-smelter sources for lead on the lead:arsenic relationships in the mainlands data set.

Depth Profiles

An analysis of the patterns of arsenic and lead results by depth shows that both contaminants are largely retained in near-surface soils at relatively undisturbed forest properties. For example, at the 59 King County mainland locations where soils were sampled to below 6 inches (to either 12 or 18 inches), over 80 percent of all arsenic results exceeding 20 ppm (n=178 samples) and more than 90 percent of all lead results exceeding 100 ppm (n=85 samples) occurred in the top 6 inches.

The maximum arsenic and lead results for the 75 locations on the mainland are plotted by the depth intervals at which they occurred in Figures 8 and 9. (For this analysis, the shallower depth is used in cases of ties). Almost all of these maximum concentrations are located within the top 6 inches. For the 59 locations sampled to below 6 inches, maximum concentrations occur below 6 inches at only 8 locations for arsenic (14%) and only 6 for lead (10%). Moreover, with the exception of a single (anomalous) high lead result at 6-12 inches, all of the highest maximum arsenic and lead results occur in the top 6 inches (see Figures 8 and 9). Average concentrations (results not shown) have a nearly identical pattern by depth.

Maximum concentrations for arsenic and lead occur fairly frequently at both 0-2 and 2-6

The lead:arsenic ratios from this model are 3.57 to 2.72 for arsenic in the range from 20 ppm to 200 ppm.

inch depths. Therefore, sampling only surface soils at 0-2 inches may not fully characterize the magnitude of soil contamination present even at relatively undisturbed forest properties; at developed properties with more physical soil disturbance, depth profiles may be even more complex. Maximum arsenic results are more common at 2-6 inches than at 0-2 inches (41 versus 26 locations, respectively, out of 75 total mainland locations); maximum lead results show the opposite pattern (29 versus 40 locations, respectively). This suggests somewhat greater downward movement for arsenic versus lead. An analysis of arsenic and lead results at 0-2 versus 2-6 inches in all 201 mainland borings confirms that arsenic is comparatively more mobile than lead overall, with only a small proportion of all borings showing greater apparent lead mobility (with these contrary results possibly caused by some degree of soil disturbance even in forest soils).

The depth profiles for the King County mainland sampling support the usefulness of the study designs, with most sampling occurring to 12 inches, for regional-scale mapping of arsenic and lead concentrations.

Variability in Soil Contamination

The total set of soils results for the King County mainland shows an overall spatial pattern, at a regional scale, consistent with the deposition of Tacoma Smelter emissions. There is also, however, significant local variability at smaller spatial scales that needs to be considered when sampling to characterize soil contamination.

A division of the total mainland study area into six subregions based on wind direction and distance from the Tacoma Smelter was introduced in the discussion of spatial pattern. (The subregions are coded as 1 through 4 from north to south along the shoreline and 5 and 6 from north to south inland; see Figure 1). The maximum arsenic and lead results for the 75 mainland sampling locations, organized by region and ranked in order of increasing magnitude within regions, are shown as bar charts on Figures 10 and 11. The figures provide a visualization of the variability across sampling locations within regions, at a scale of up to several miles, as well as between regions. Maximum arsenic and lead results can clearly be quite dissimilar within small regions of the mainland study area. In all six regions, the lead variability (measured, for example, as the ratio of the largest to the smallest maximum concentrations) is greater than the arsenic variability. The biggest differences among regions are seen to occur for the highest maximum concentrations. It is notable, however, that all six regions have one or more maximum arsenic results equal to or less than 24 ppm, and one or more maximum lead results less than or equal to 62 ppm. Thus, relatively low maximum concentrations occur in all parts of the study area and are no guarantee of similarly low concentrations nearby.

For 63 of the 75 mainland sampling locations, soil results are available from 3 borings separated by no more than a few hundred feet. Even at this small spatial scale significant

differences in soil contamination were observed. The maximum concentrations of arsenic and lead in each boring are convenient measures of the potential magnitude of soil contamination indicated by that boring. Two comparisons of the largest and smallest maximum concentrations across the cluster of three local borings are used to assess local variability: their ratio (or relative difference) and their absolute difference, in ppm. With each measure of variability shown on one axis, the results for one location become a point in an X-Y scatterplot. Such scatterplots for the maximum arsenic and lead results from borings within 63 mainland locations are provided as Figures 12 and 13. Both arsenic and lead frequently show ratios greater than 2 (see the X-axis), indicating relative differences up to several hundred percent at a spatial scale of no more than a few hundred feet. The absolute differences for arsenic are often more than the MTCA cleanup level of 20 ppm, and the lead differences are often more than 100 ppm. Thus, even closely-spaced soil samples can show significantly different results. One, or a few, samples may not adequately characterize the magnitude of such locally-variable soil contamination. This local variability also supports the conclusion that the regional scale sampling to date on the King County mainland probably does not characterize the absolute highest concentrations of arsenic or lead that occur.

This type of local variability in soil contaminant concentrations is consistent with the findings from the earlier Vashon-Maury Island sampling. It probably represents a combination of factors: differences in original deposition of airborne contaminants, the elevation and slope characteristics of sampled locations, differences in soil types and contaminant fate processes, and variable degrees of soil disturbance post-deposition.

Combined Vashon-Maury Island and King County Mainland Results

The results of soil sampling at relatively undisturbed forest locations on Vashon-Maury Island have been reported previously. With completion of regional-scale sampling on the King County mainland, soil arsenic and lead data are now available for a large downwind area in King County extending from less than 3 miles to more than 26 miles from the former Tacoma Smelter location in Ruston, Washington. This large study area includes a range of wind directions of varying frequencies (see Figure 1). A summary of the combined Vashon-Maury Island and mainland data sets provides an overview of the current understanding of the regional-scale magnitude and extent of soil contamination from smelter emissions in King County. (A similar study in Pierce County is now underway).

A total of 236 locations has been sampled in King County: 161 on Vashon-Maury Island and 75 on the mainland. Scatterplots of the maximum arsenic and lead results at these 236 locations, as mapped on Figures 2 and 4, versus distance from the smelter tall stack (in miles) are shown on Figures 14 and 15. These concentration versus distance plots both show a clear gradient of decreasing maximum concentrations with increasing distance from the smelter, with only a small number of anomalous lead results. The Vashon-Maury Island results thus provide a

larger-scale context in which to understand the mainland results; extending the data set to include the higher impacts at Vashon-Maury Island locations closer to the smelter makes the overall spatial pattern clearer. The King County mainland results are part of a larger-scale concentration gradient from the smelter.

All wind directions are included in Figures 14 and 15; separate plots of the results by wind sector would show the expected pattern of higher soil concentrations, extending farther from the smelter, in more frequent downwind directions. The scatterplots of maximum concentrations in Figures 14 and 15 both show substantial variability at any one distance from the smelter. That is partly a result of combining data from all wind sectors, but it also reflects the characteristic local variability discussed above.

A scatterplot (with log-scaled axes) showing the overall relationship between maximum arsenic and maximum lead concentrations for all sampled areas of King County is provided as Figure 16 (compare to Figure 6 for the mainland only). The strong relationship between arsenic and lead is apparent.

Conclusions

Soil arsenic and lead results from 75 King County mainland sampling locations, with a total of 624 soil samples, provide a regional-scale understanding of the magnitude and extent of soil contamination downwind from the former Tacoma Smelter. Soil contamination has been documented to distances over 20 miles from the smelter. The highest mainland arsenic and lead concentrations found were 260 ppm and 790 ppm, respectively. Compared to the MTCA cleanup levels for unrestricted land use, arsenic contamination appears more widespread than lead contamination on the mainland.

Evaluations of the King County mainland results, together with previous results from Vashon-Maury Island, show contaminant concentration gradients with distance from the smelter, an association of greater soil impacts in more frequent downwind directions, and a strong correlation between arsenic and lead concentrations (and with additional tracer element results to be reported). These evaluations identify the former Tacoma Smelter as the dominant source for arsenic and an important source for lead; some additional sources for lead on the mainland (e.g., emissions from leaded gasoline) are also indicated.

The spatial patterns of soil contamination on a regional scale (and at some distance from major roadways) are thus consistent with smelter emissions as the primary source. Those spatial patterns identify areas of King County that are of comparatively greater concern for potential exposures and health risks from soil arsenic and lead contamination. Substantial local variability in the magnitude of contamination has also been shown to occur. As a result, the results reported here should not be used to interpolate specific concentrations for other unsampled locations. The

best use of the regional-scale data is to suggest the likely ranges within which soil contamination could be found in various regions of the total King County study area (see, for example, Figures 10, 11, 14, and 15). The low sampling density, limited availability of forested sampling areas, and significant local variability in results in these initial studies make it likely that the absolute maximum arsenic and lead values in King County soils from smelter emissions have not been detected. The significant local variability also means that one or a few soil samples will often not accurately characterize the magnitude of contamination on a property.

The results reported here represent sampling in those areas - relatively undisturbed forest soils - where soil contamination from smelter emissions is expected to be greatest. This approach was adopted to meet the objective of characterizing the possible (upper bound) magnitude and extent of soil contamination. Arsenic and lead in forest soils are mostly retained within the top 6 inches or so of the soil column. Developed properties with a history of soil disturbance can have more complex contaminant depth profiles, with contamination extending deeper. These regional-scale results should therefore not be extrapolated uncritically to other, non-forested locations such as residential properties, where depth profiles may differ significantly and soil-disturbing actions can, but do not always, reduce the maximum contaminant concentrations.

Next Studies

The Department of Ecology is currently working with the Tacoma Pierce County Health Department on a similar study of magnitude and extent of plume contamination in Pierce County. Field sampling will take place during the Spring/Summer of 2002.

As with the initial Vashon-Maury Island study where the next step taken was sampling of child-use areas, Ecology will work with PHSKC on investigating contamination in child-use areas in south King County. Sampling will be focused in areas where contamination levels are likely to be highest. Scoping the details of this study will take place in the Fall of 2002, with field sampling to follow in the Summer of 2003.

Attachments

Tables

Table 1: King County Mainland Arsenic and Lead Results [624 samples]

Table 2: Maximum Arsenic and Maximum Lead Results by Location

Figures

Figure 1: Map of Sampling Locations and Location Codes

Figure 1a: Map of Sampling Design by Location

Figure 2: Map of Maximum Arsenic Results, Vashon-Maury Island and King County Mainland

Figure 3: Statistical Distribution of Maximum Arsenic Results, King County Mainland

Figure 4: Map of Maximum Lead Results, Vashon-Maury Island and King County Mainland

Figure 5: Statistical Distribution of Maximum Lead Results, King County Mainland

Figure 6: Maximum Arsenic versus Maximum Lead Scatterplot, King County Mainland

Figure 7: Map of Maximum Lead:Maximum Arsenic Ratios, King County Mainland

Figure 8: Maximum Arsenic Results versus Sampling Depth, King County Mainland

Figure 9: Maximum Lead Results versus Sampling Depth, King County Mainland

Figure 10: Variability in Maximum Arsenic Results Within and Between Regions of King County Mainland

Figure 11: Variability in Maximum Lead Results Within and Between Regions of King County Mainland